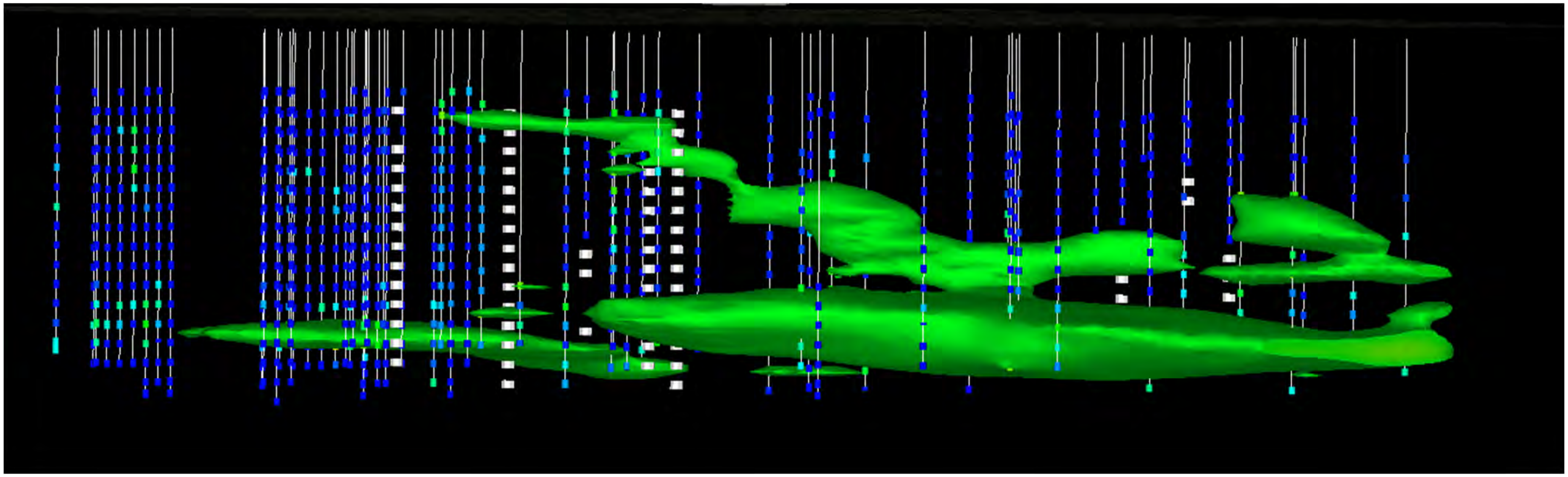
Interpreting and Responding to Intensified Site Characterization Results



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ARCADIS

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14. ABSTRACT

High-resolution site characterization is being applied at an increasing number of sites especially large-plume sites with long-standing chlorinated solvent source zones. This allows us to improve remedy design and operation, but it can also add to the challenge of regulatory closure, particularly in jurisdictions that require all groundwater to reach MCLs including locations where groundwater cannot be extracted at rates that would allow use for water supply. Common patterns are emerging from these sites, including ? Heterogeneous, anisotropic aquifer matrix structure, even at sites that were expected to be relatively homogeneous ? Contaminant mass transport focused in a small fraction of the aquifer matrix crosssection (more than 90% of the mass transport is occurring in less than 10% of the aquifer matrix) ? Extremely small transverse dispersivities; and ? In locations where the aquifer matrix has been exposed to soluble contaminants over extended periods, a significant portion of the contaminant mass resides in lowerpermeability zones. In many locations, there is a large divergence between contaminant concentrations in groundwater extraction wells (or monitoring wells pumped at modest to high specific flow rates) and small-scale sample collections from lower-permeability zones. Contaminants located in the lower-permeability zones can be very difficult to treat and the challenge of meeting MCLs across all permeabilities is significant. This paper provides details of recent high-resolution sampling programs at large plume sites and examines how site hydrogeology and contaminant chemistry interacted to create the distribution patterns that are being observed. Then, the paper examines the prospects for remedial action in these zones, with data from multiple technologies in heterogeneous aquifers.

15. SUBJECT TERMS

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INTERPRETING AND RESPONDING TO INTENSIFIED SITE CHARACTERIZATION RESULTS

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High-resolution site characterization is being applied at an increasing number of sites, especially large-plume sites with long-standing chlorinated solvent source zones. This allows us to improve remedy design and operation, but it can also add to the challenge of regulatory closure, particularly in jurisdictions that require all groundwater to reach MCLs, including locations where groundwater cannot be extracted at rates that would allow use for water supply.

Common patterns are emerging from these sites, including:

- Heterogeneous, anisotropic aquifer matrix structure, even at sites that were expected to be relatively homogeneous;
- Contaminant mass transport focused in a small fraction of the aquifer matrix cross-section (more than 90% of the mass transport is occurring in less than 10% of the aquifer matrix);
- Extremely small transverse dispersivities; and,
- In locations where the aquifer matrix has been exposed to soluble contaminants over extended periods, a significant portion of the contaminant mass resides in lower-permeability zones.

In many locations, there is a large divergence between contaminant concentrations in groundwater extraction wells (or monitoring wells pumped at modest to high specific flow rates) and small-scale sample collections from lower-permeability zones. Contaminants located in the lower-permeability zones can be very difficult to treat and the challenge of meeting MCLs across all permeabilities is significant.

This paper provides details of recent high-resolution sampling programs at large plume sites and examines how site hydrogeology and contaminant chemistry interacted to create the distribution patterns that are being observed. Then, the paper examines the prospects for remedial action in these zones, with data from multiple technologies in heterogeneous aquifers.

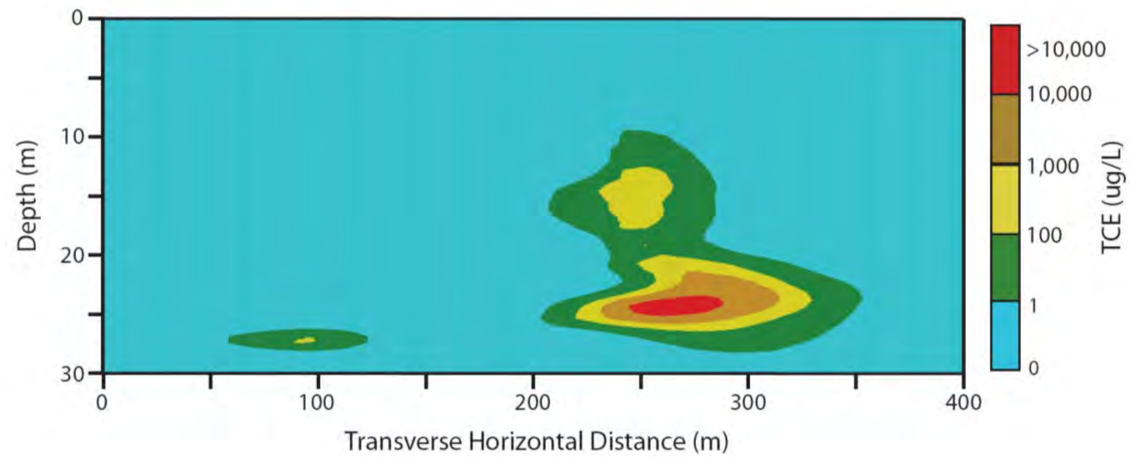
Outline

- Patterns Emerging from Intensified Site Characterization
  - Heterogeneous, anisotropic structure
  - Extreme low dispersivities
- Large-Plume Conceptual Model
  - Transport in transmissive zones
  - Storage in less-transmissive zones
  - Mass exchange rates are a critical factor
- New Opportunities Arise
  - Remedial strategies (e.g., directed groundwater recirculation)
  - Compliance (e.g., dynamic groundwater monitoring)
- Questions and Discussion

Beaver Island, Michigan

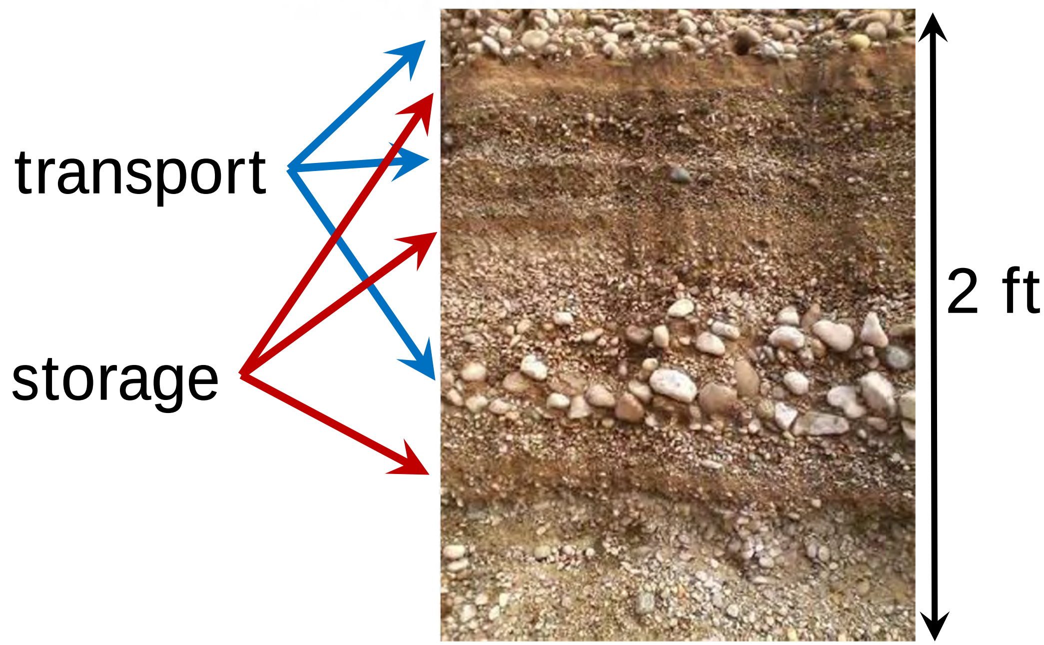
Impacts and Opportunities

- Contaminant mass transport is often concentrated in a small portion of the aquifer cross-section
- Remedies can be designed to take advantage of this distribution pattern



<u>However,</u>

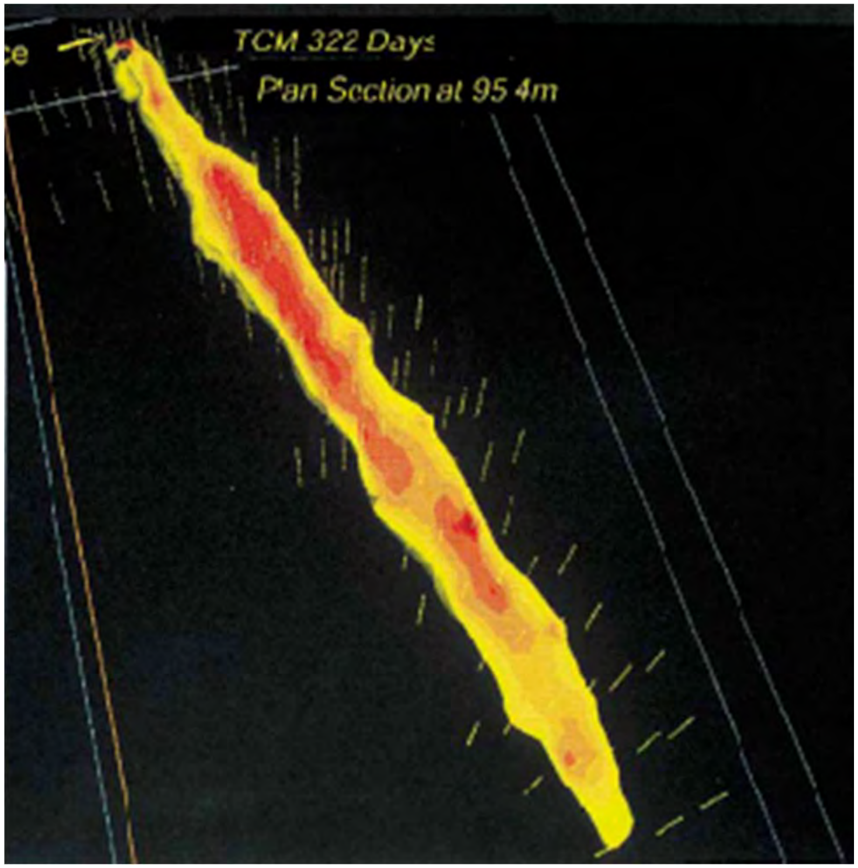
- High-resolution sampling is also unmasking contaminant mass storage – High-C, Low-K zones
    - Mass transfer behavior controls remedy design and success
    - Need to rationalize application of compliance standards



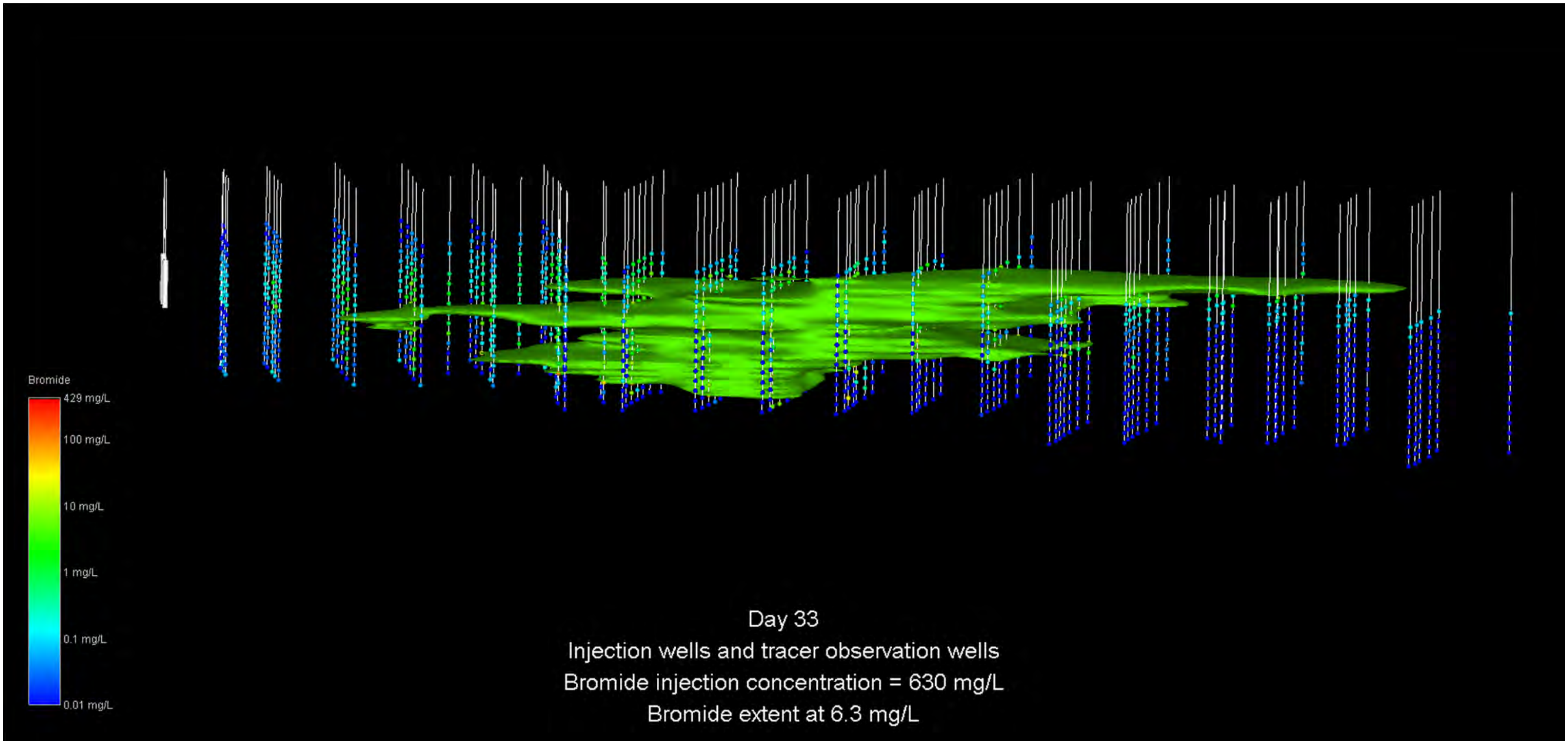
Field research repeatedly confirms that transverse dispersivity is near-zero

Borden aquifer studies – Rivett, Feenstra and Cherry

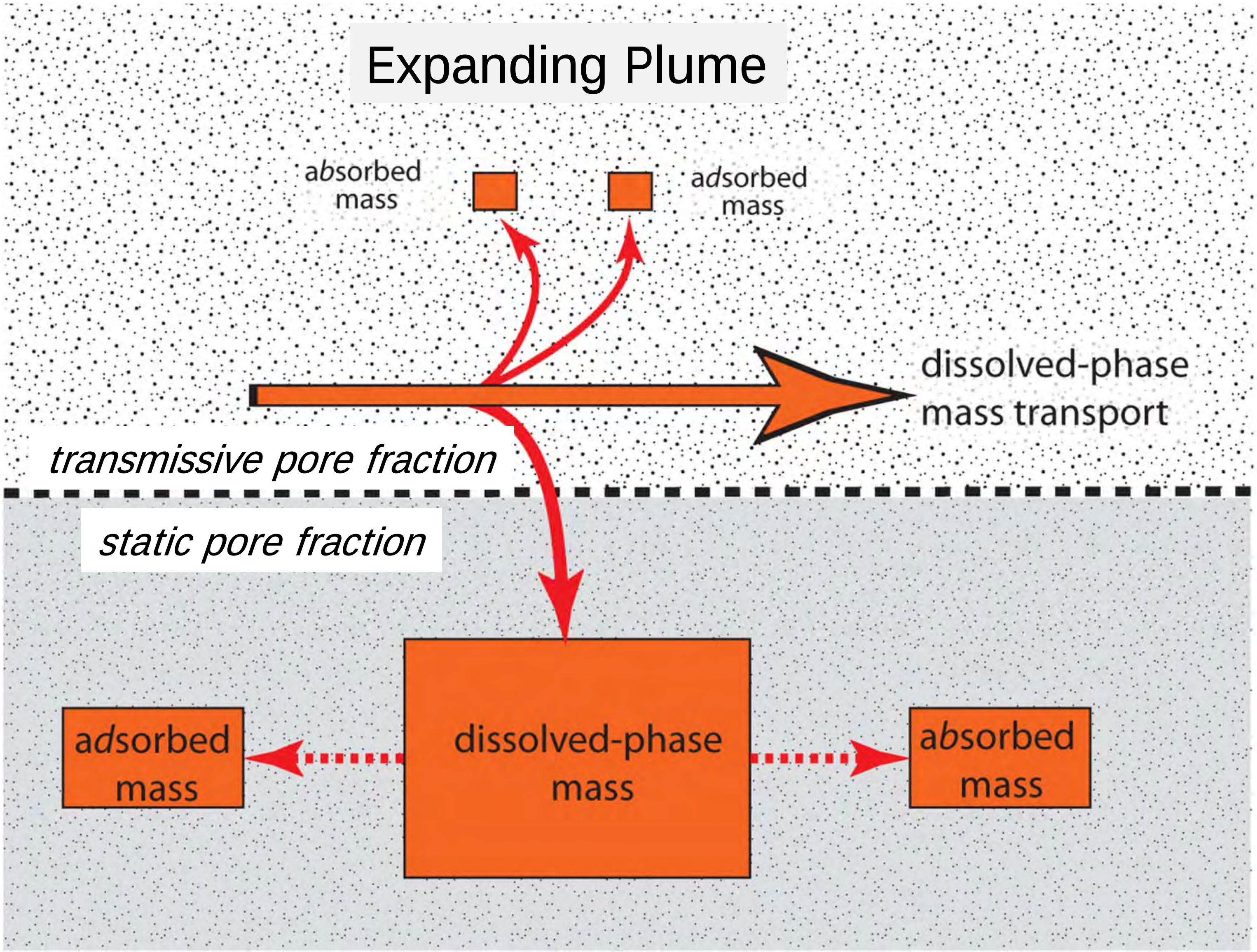
Natural aquifers show near-zero transverse dispersivity



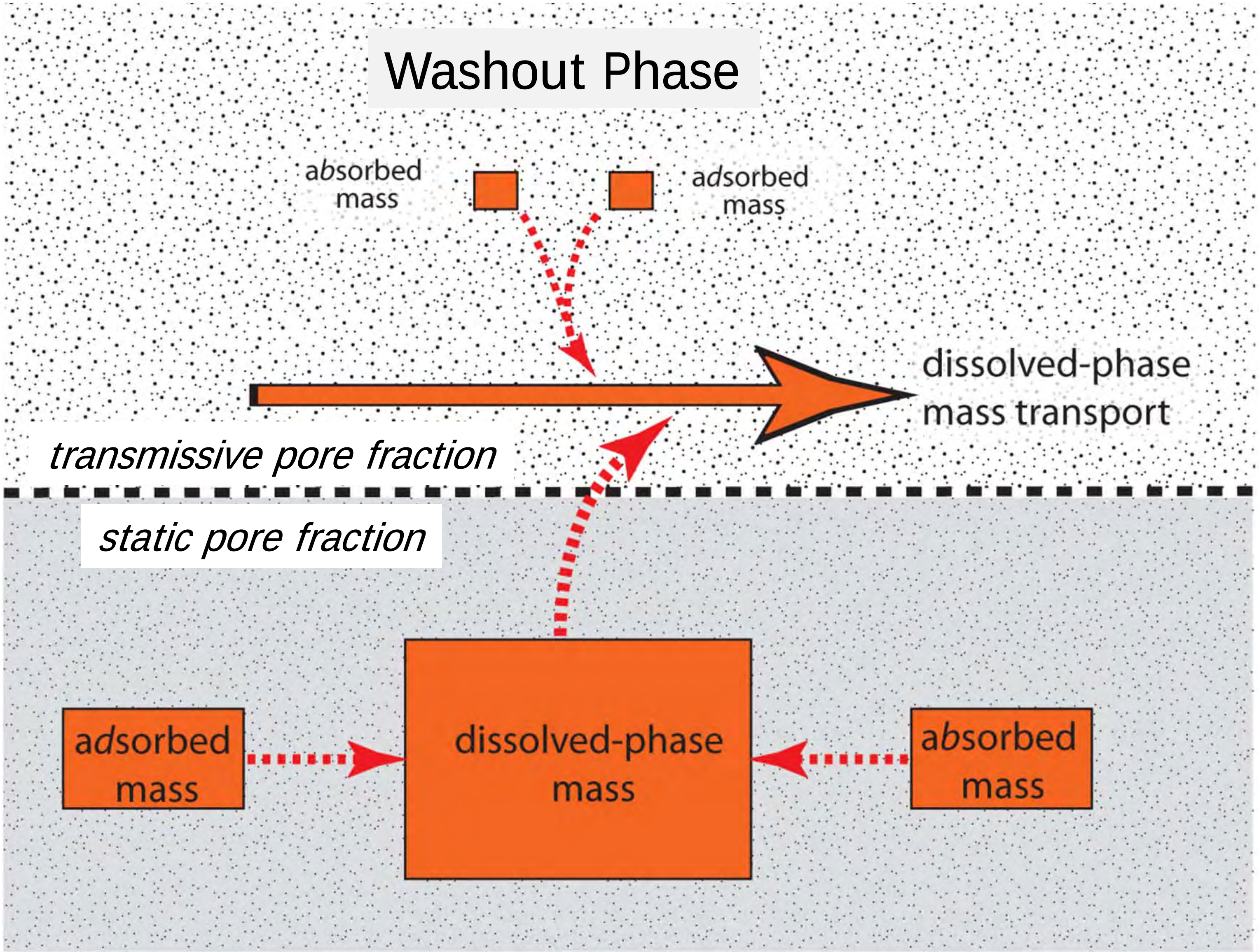
Cape Cod Tracer Studies – A broad spectrum of transport velocities



Multi-Domain Transport and Storage



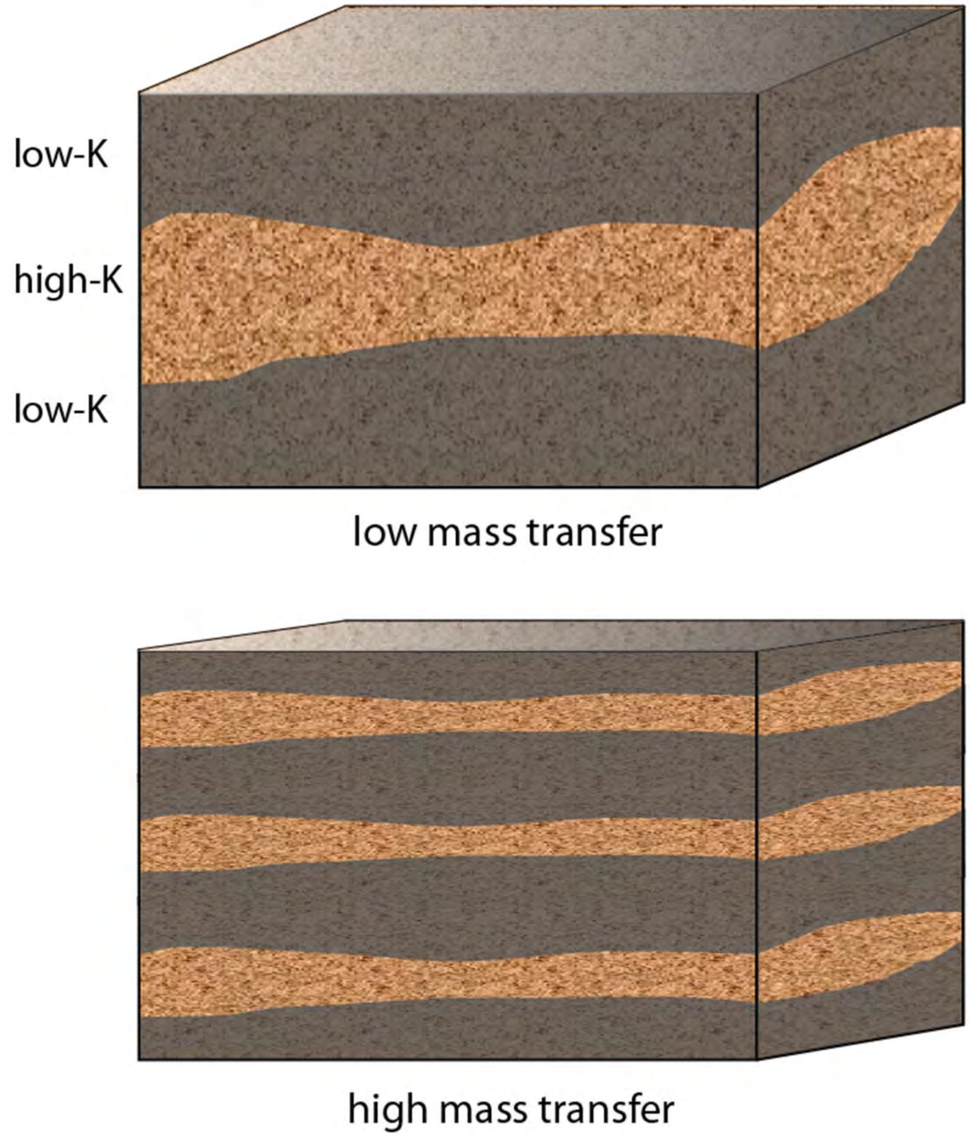
Multi-Domain Transport and Storage



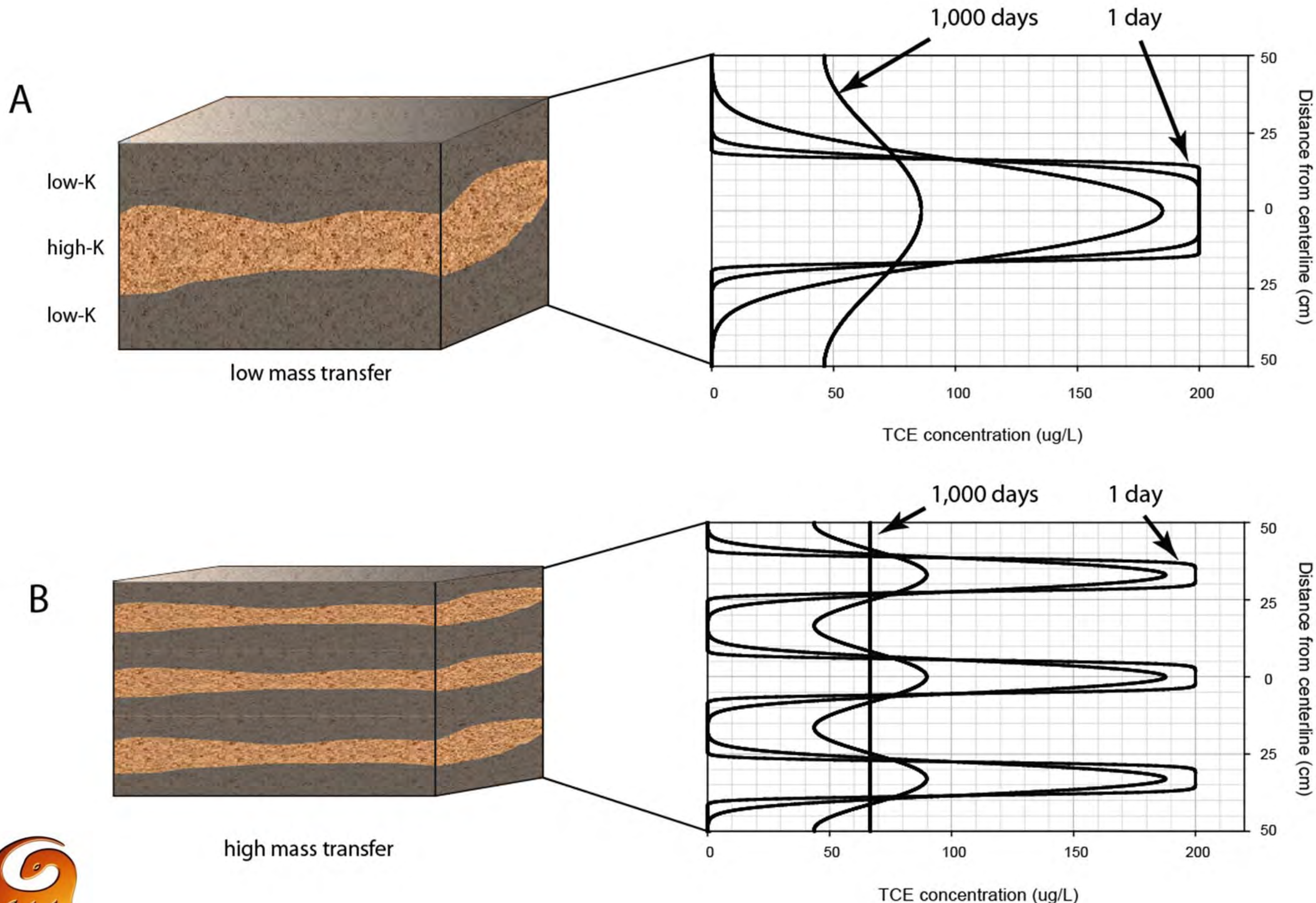
Aquifer Matrix Effects

- Two aquifer blocks with equal:
  - Average hydraulic conductivity
  - Mobile porosity
  - Groundwater transport velocity

- In the high-mass-transfer geometry, the rate of diffusive migration into the low-K zones is approximately 10-fold greater than for the low-mass-transfer case.
  - Increased exchange surface area
  - Decreased diffusion path lengths



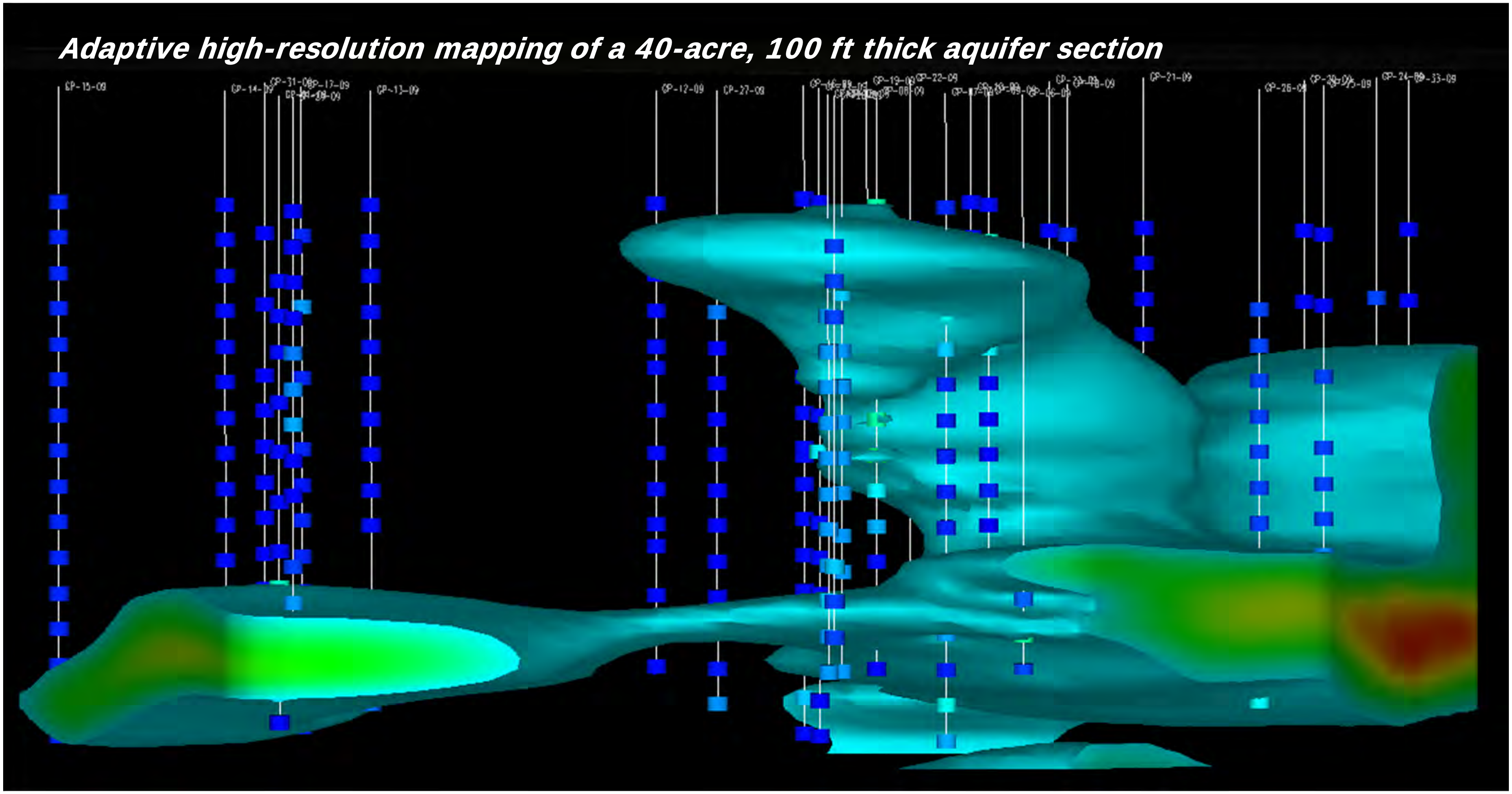
Matrix Structure Controls Diffusion Impact



Re-Thinking Monitoring Wells

- 10-year life-cycle cost of a single monitoring well ~ $150,000 (construct, develop, monitor and report quarterly, abandon)
- Better approach – separate site characterization from monitoring well construction – characterize then determine most effective monitoring well locations.
- Yields a significant reduction in the number of monitoring wells

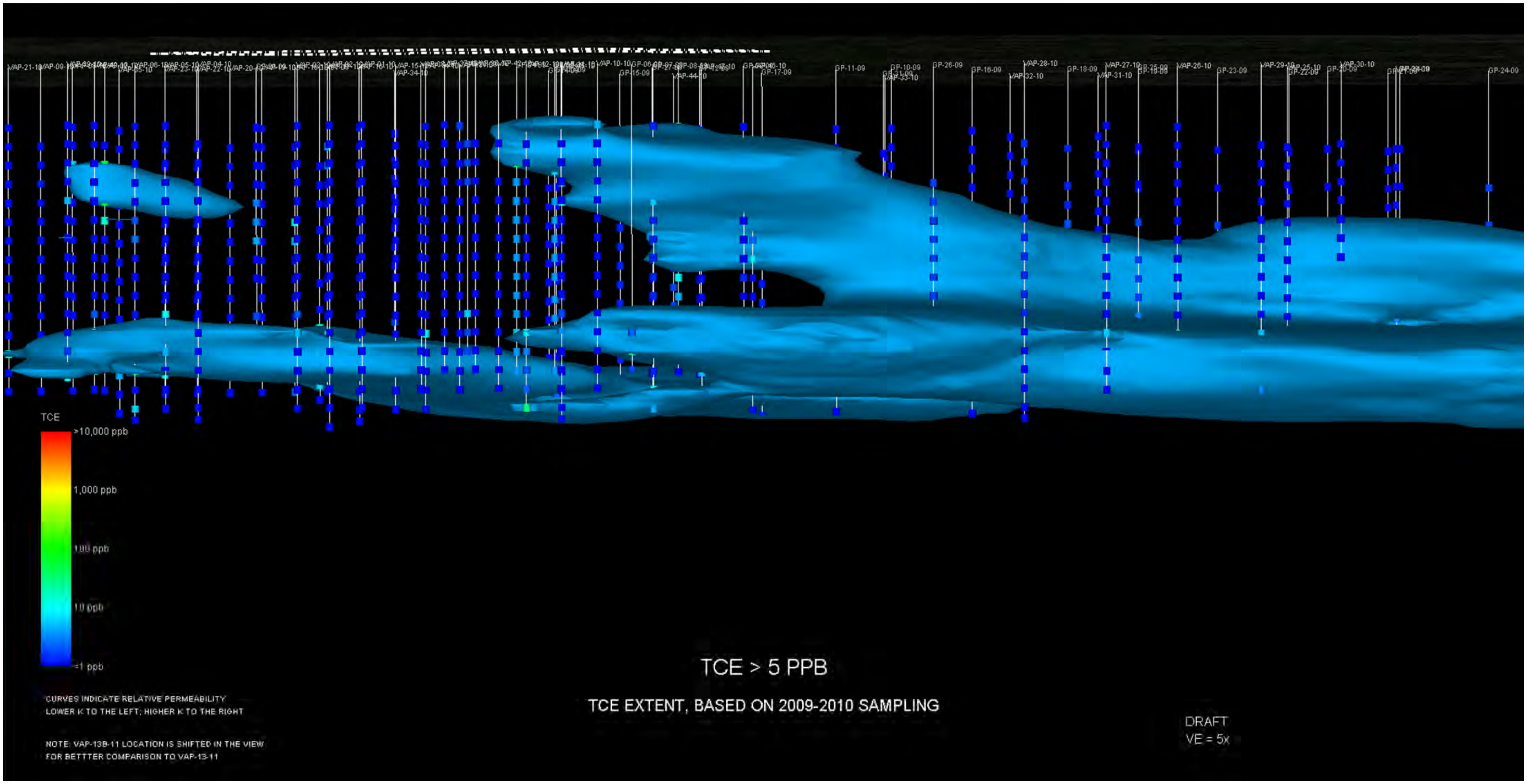
Mapping at High Definition – Collaborative Demonstration with Amsted Industries Muskegon, Michigan Site



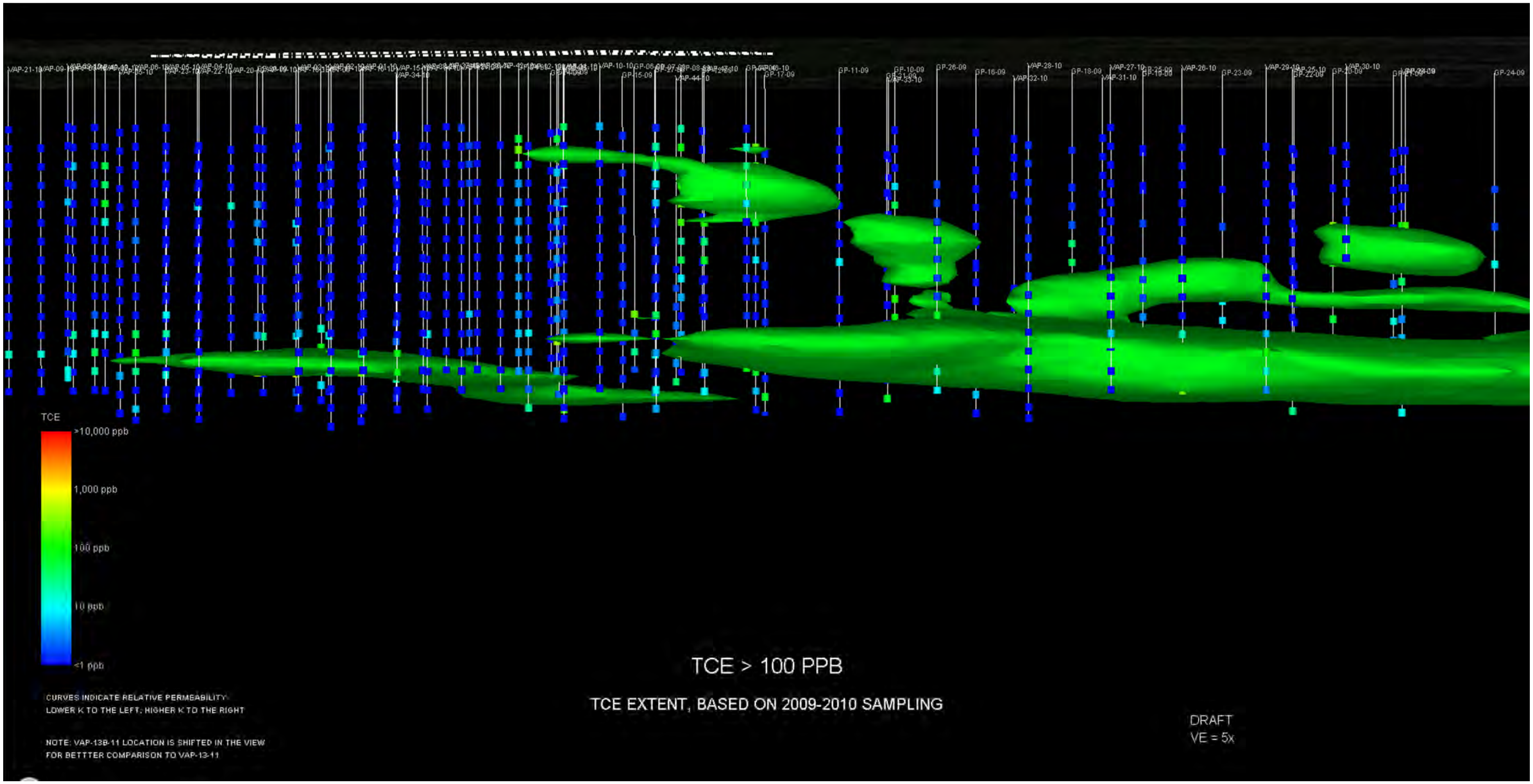
Muskegon Site - Conceptual Site Model

- High-K sandy aquifer
- 100 ft thickness
- Multiple known sources in the area
- TCE used and disposed via seepage lagoon
- Seepage lagoon excavated in 1975
- Conventional monitoring wells indicated 100 ug/L TCE in groundwater, heading off-site

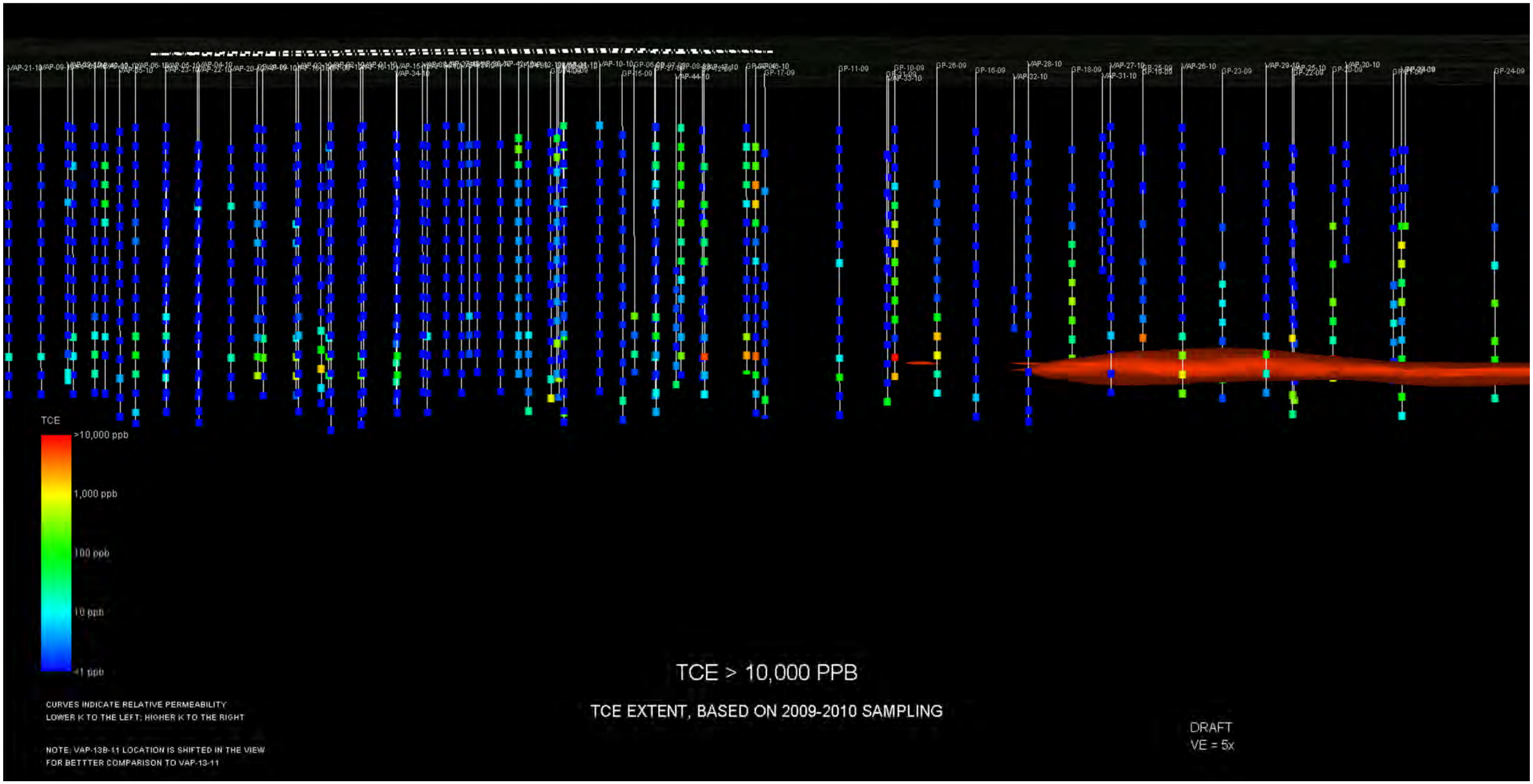
Muskegon Site – 5 ug/L envelope



Muskegon Site – 100 ug/L envelope

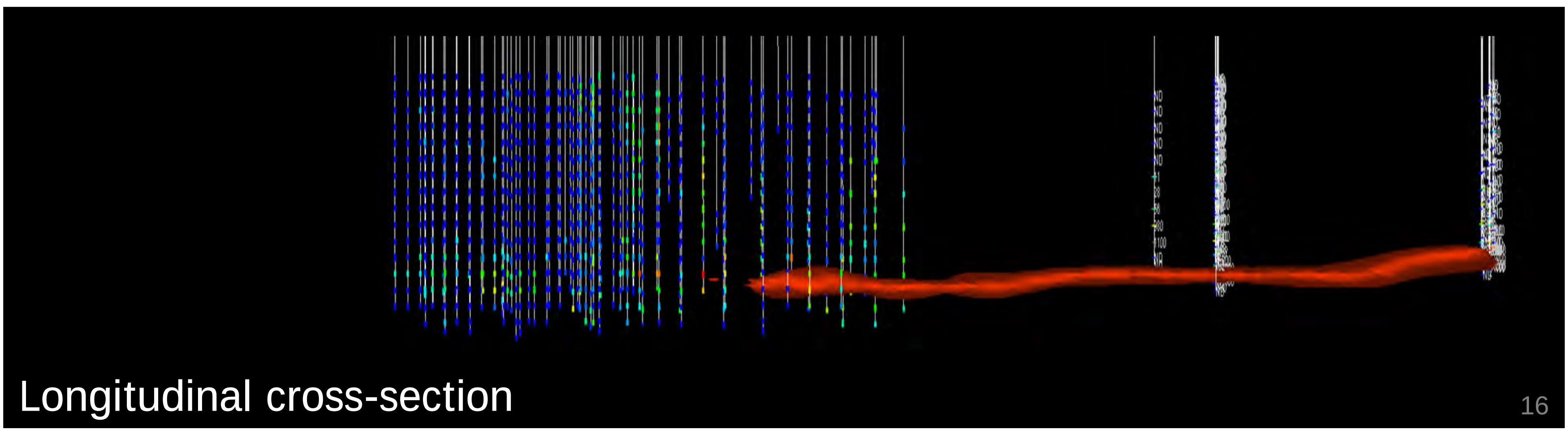


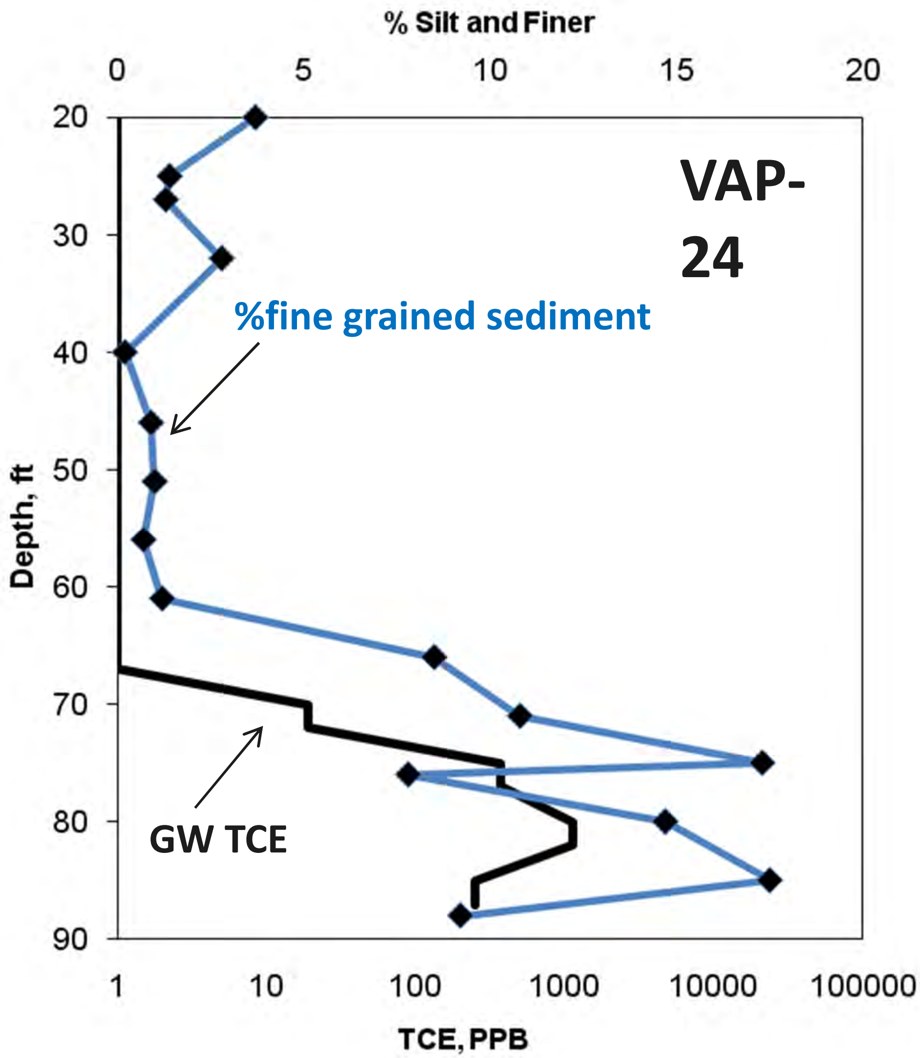
Muskegon Site – 10,000 ug/L envelope




Plan view
TCE
>10,000 ppb
1,000 ppb
100 ppb
10 ppb
<1 ppb
TCE > 10,000 PPB
TCE EXTENT, BASED ON 2009-2010 SAMPLING
CURVES INDICATE RELATIVE PERMEABILITY
LOWER K TO THE LEFT; HIGHER K TO THE RIGHT
DRAFT

2,600 ft


Longitudinal cross-section



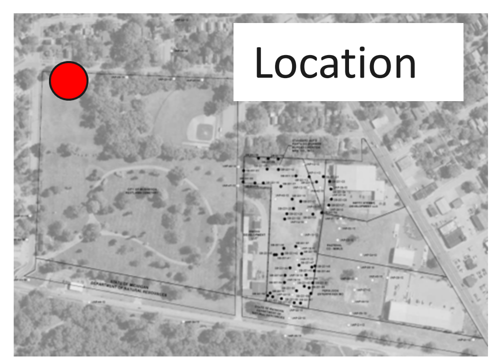
Highest TCE concentrations are in lower permeability sediments

3-5% silt and clay
95-97% sand

<1 ppb TCE

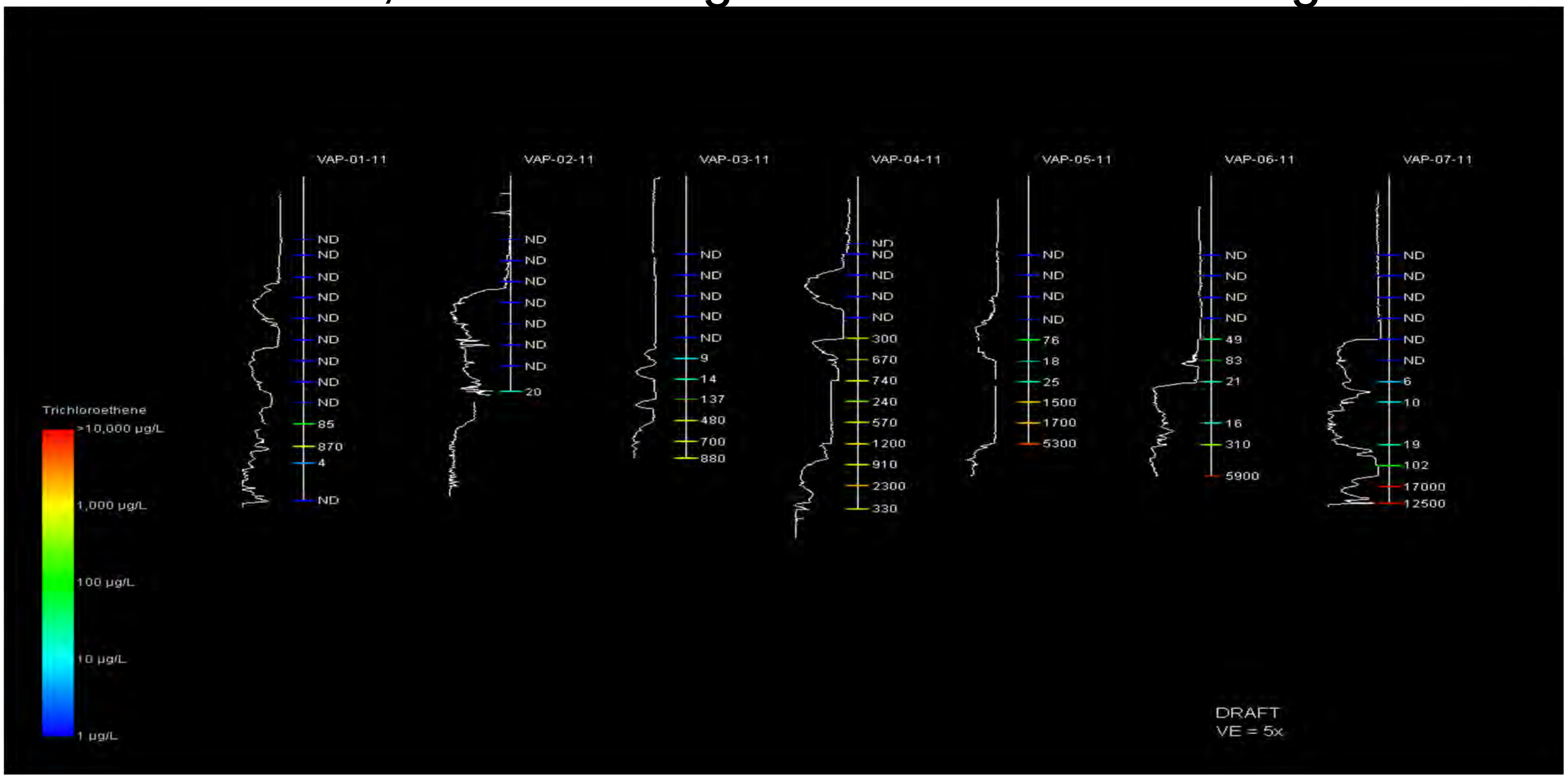
10-20% silt and clay
80-90% sand

10-10,000 ppb TCE



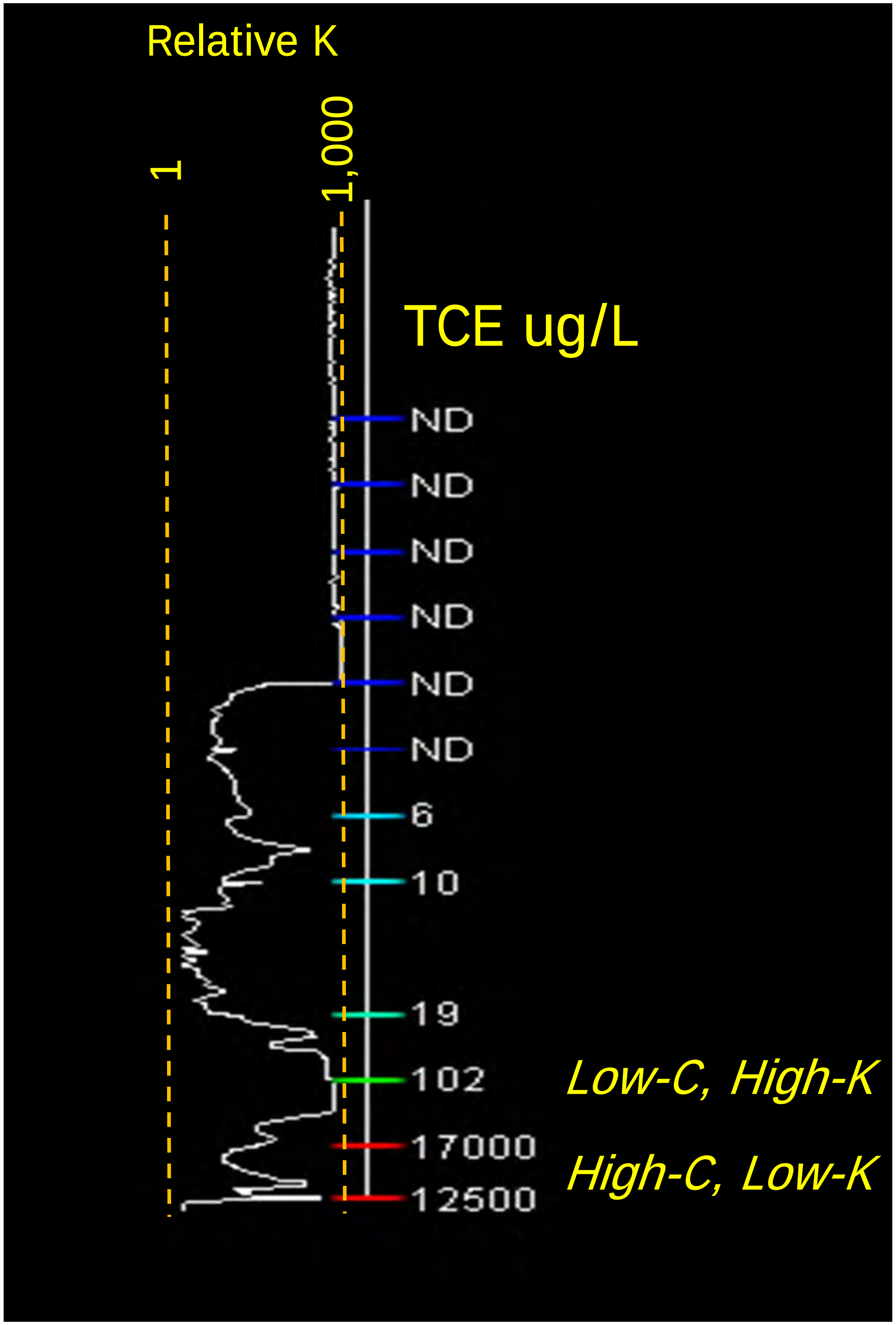
Muskegon Site – Downgradient Transects

Transect 1 – 2,600 ft downgradient from source lagoon

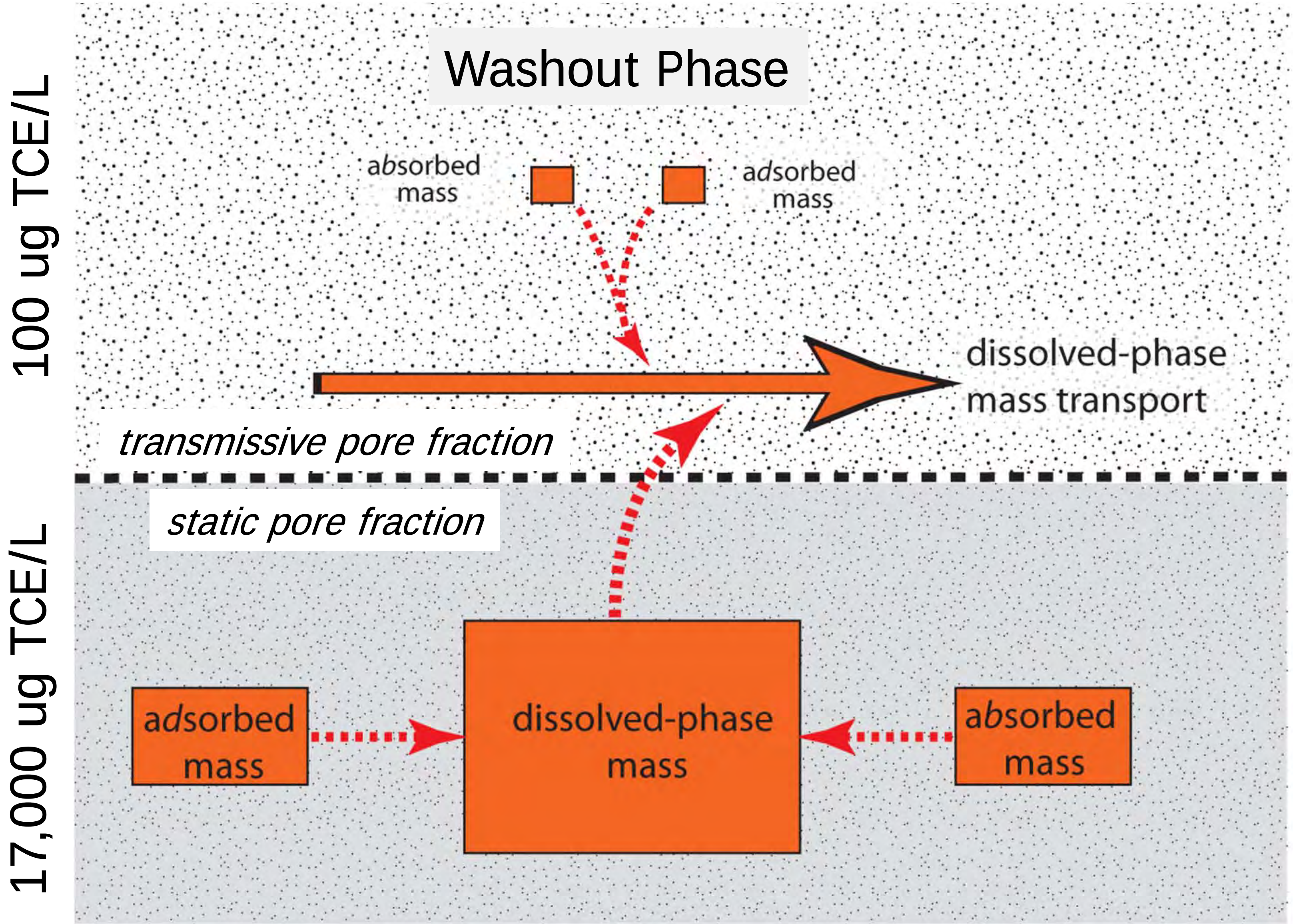


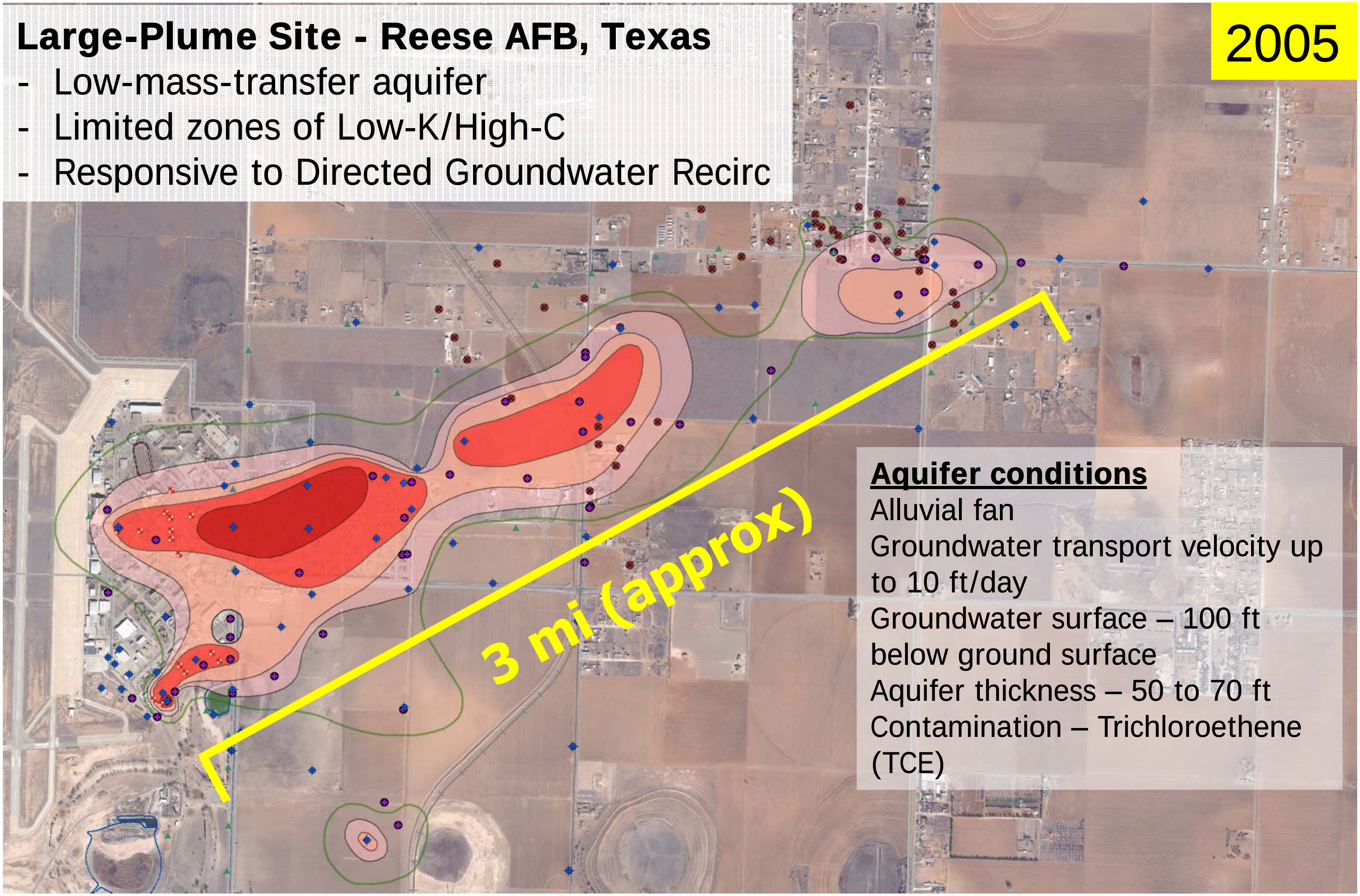
2,600 ft Downgradient

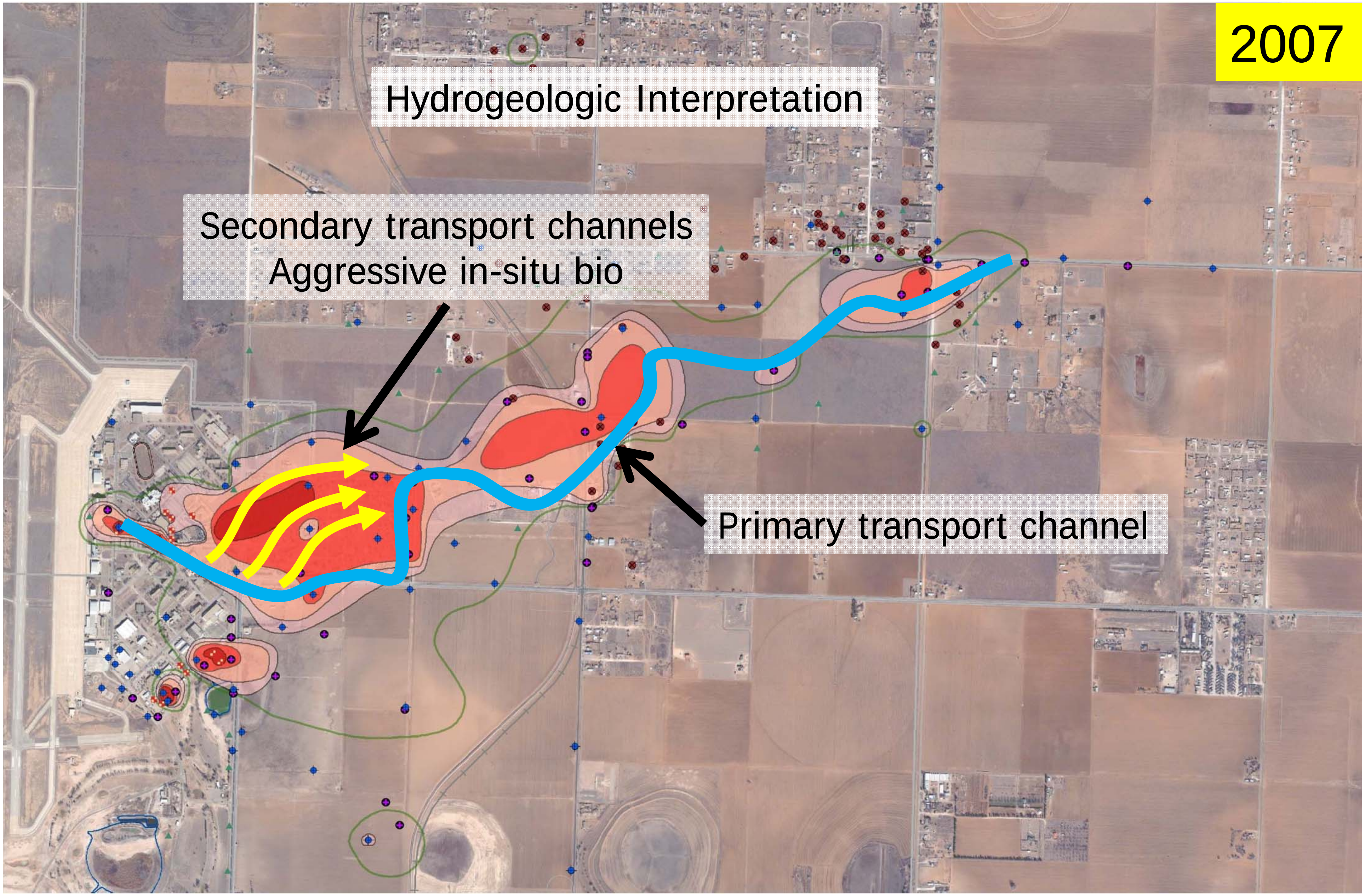
- Maximum hydraulic response on the Waterloo Profiler over a large portion of the cross-section
- More than ½-mile and 35 years from the source zone.
- TCE concentrated in lower-K zones
- A large plume passed by here



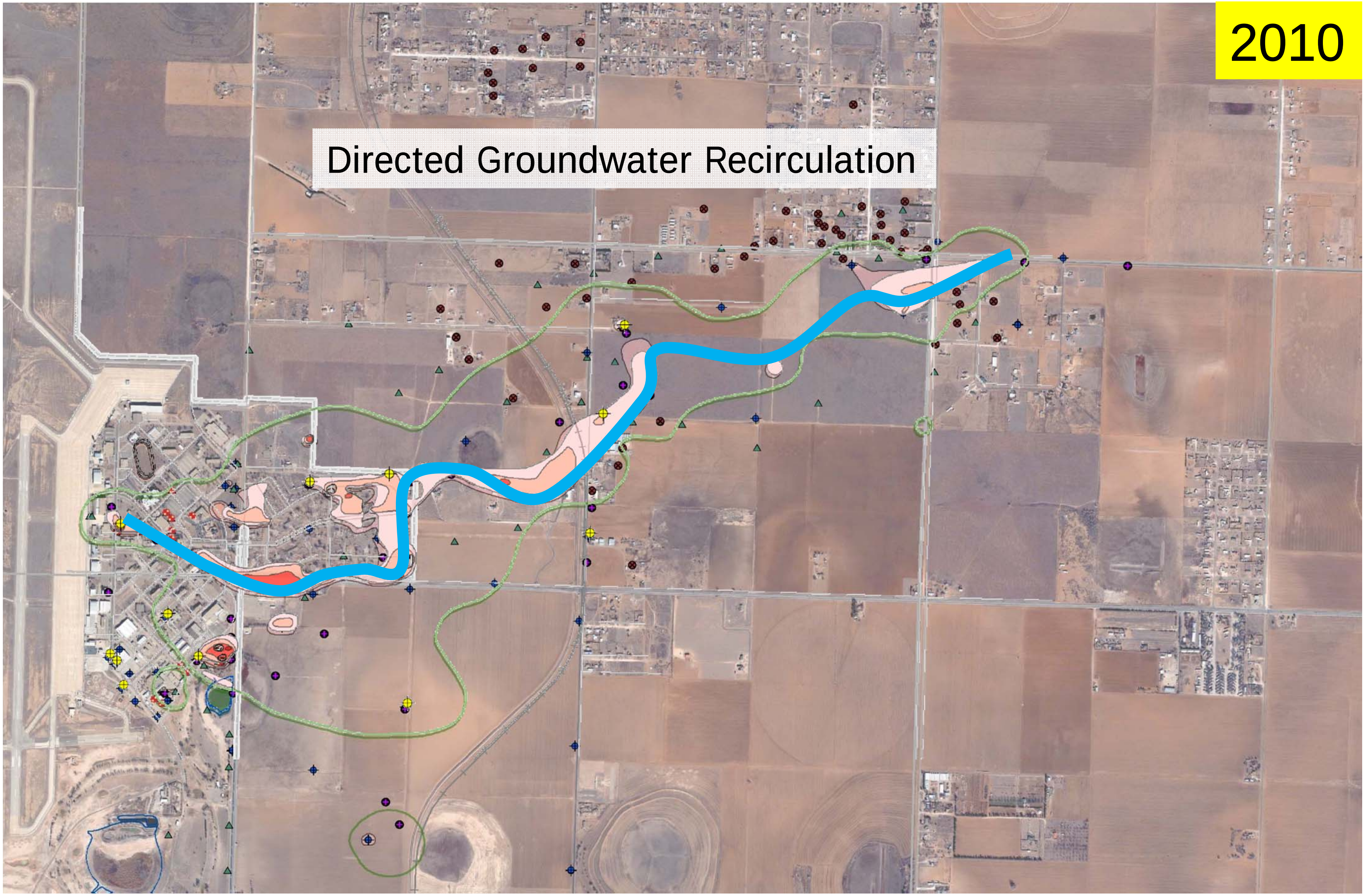
Interpreting TCE distribution – Washout Model

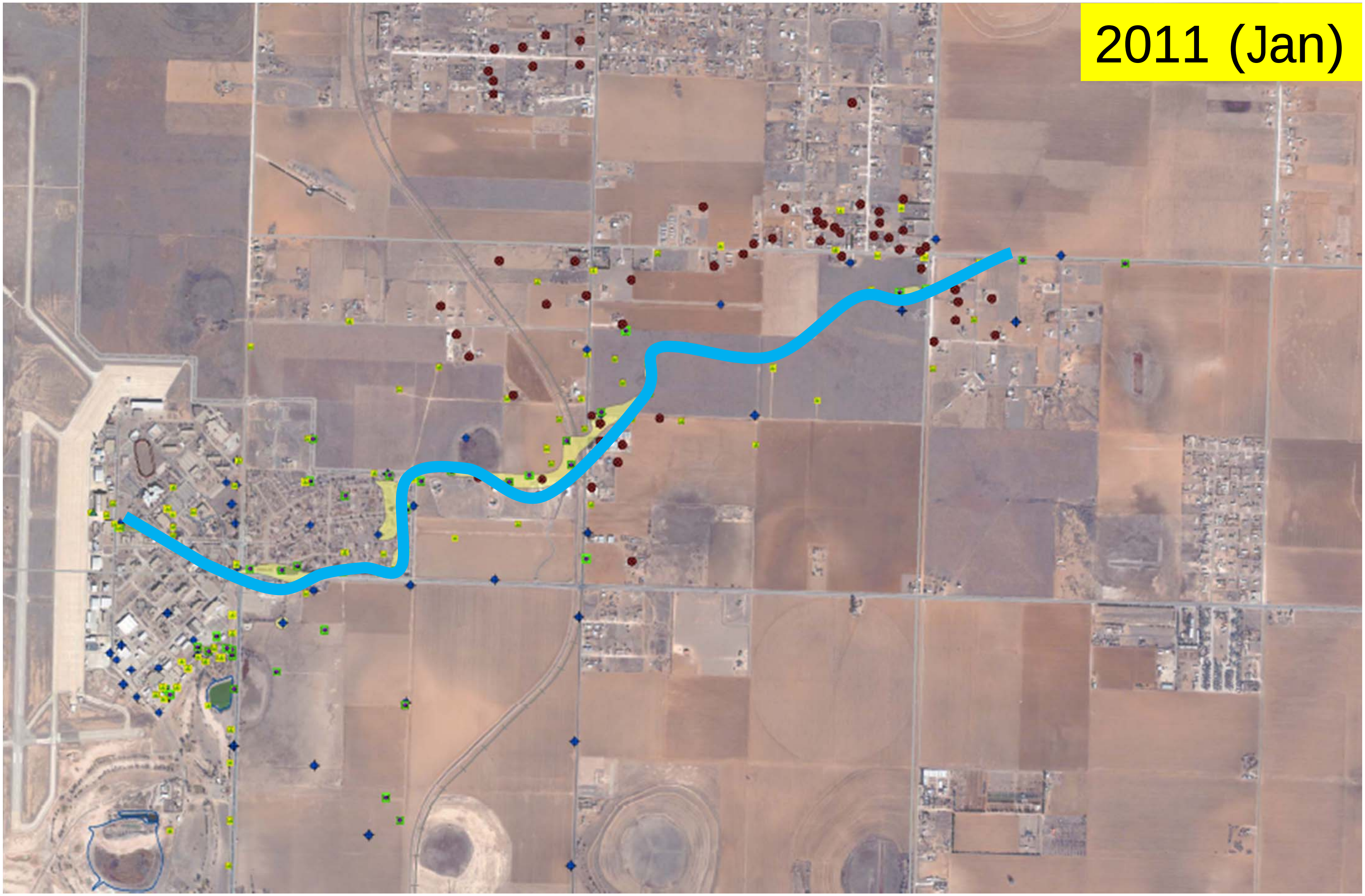



Large-Plume Site - Reese AFB, Texas
- Low-mass-transfer aquifer
- Limited zones of Low-K/High-C
- Responsive to Directed Groundwater Recirc
2005
3 mi (approx)
Aquifer conditions
Alluvial fan
Groundwater transport velocity up to 10 ft/day
Groundwater surface – 100 ft below ground surface
Aquifer thickness – 50 to 70 ft
Contamination – Trichloroethene (TCE)



2007
Hydrogeologic Interpretation
Secondary transport channels
Aggressive in-situ bio
Primary transport channel


2010
Directed Groundwater Recirculation


2011 (Jan)

Argument for Rational Application of Compliance Standards

- Higher-resolution mappings are unmasking complex contaminant distribution patterns
- High-K (transport) zones can meet standards, while adjacent low-K (storage) zones exceed standards
- Remedy designs need the higher-resolution mappings to be successful, *however:*
- Low-K zones cannot be treated to compliance.
- Dynamic groundwater monitoring is a potential solution:
  - Separate site characterization from compliance monitoring
  - Build and sample monitoring wells to reflect protected use (i.e. drinking water protection)
  - Avoids inevitable application of TI arguments in low-K zones

Questions and Discussion

For more information, contact:

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